ZERO/LOW EMISSION AND CO-PRODUCTION ENERGY SUPPLY STATION

Background of the Invention

The present invention relates to energy supply systems, and more particularly relates to an energy supply system that employs an energy supply station for producing and delivering hydrogen and/or electricity to users such as vehicles.

Energy supply stations are known and exist. A conventional energy supply station is a stand-alone station that can be configured to provide a consumable fuel, such as a hydrocarbon fuel or hydrogen. Alternatively, the station can be configured to generate electricity. A drawback of these types of stations is that they provide only single purpose services, either delivering fuel or producing electricity. Furthermore, they do not, along the supply chains of fuel and electricity, reduce the overall levels of emissions discharged into the environment.

Moreover, environmental and political concerns associated with traditional combustion-based energy systems and stations, such as internal combustion engines or any onsite and central electricity generation plants, are elevating interest in alternative clean (e.g., green) types of energy systems. Thus, there exists a need in the art for a relatively clean high performance energy supply station. In particular, an improved low emission station employing one or more types of chemical converters would represent a major improvement in the industry. Additionally, a low emission energy supply station that is capable of delivering hydrogen fuel and/or electricity to users such as vehicles would also represent a major advance in the industry.

Summary of the Invention

The station of the present invention employs a hybrid reformer/fuel cell system used to create a zero/low emission service station utilizing existing transportation fuel infrastructure without burdening the existing electric power infrastructure, while concomitantly maintaining an environmental balance that eliminates or significantly reduces the CO_2 component from greenhouse emissions. Traditional transportation fuels

such as gasoline, diesel fuel, natural gas, methanol or biogas, are converted to hydrogen and electricity for use in zero or low emission vehicles, such as fuel cell vehicles, battery powered vehicles or a hybrid of such vehicles. Excess electric power generated by the station can be utilized onsite, nearby or dispensed to an electric power grid.

The hybrid reformer/fuel cell system can be a two in one system providing both hydrogen and electricity, or can be configured to provide either electricity or hydrogen. The two in one system arrangement is advantageous since can be configured to share major components between a reformer subsystem and a fuel cell subsystem, and is capable of providing diverse energy services in a baseload operation. This allows the system operational efficiency, cost effectiveness and versatility. A major attractiveness of the system is its environmental advantage - zero emission of SO_x, NO_x, or CO_2, in addition to the system's capital and operational economy.

The hybrid system can employ a chemical converter. The chemical converter may be operated as a reformer. When operated as a steam reformer, thermal energy for the endothermic steam reforming reaction is provided from an external heat source by radiation and/or convection. A shift reaction from the molecular species of hydrogen, carbon monoxide and steam produces a stream of hydrogen, carbon dioxide and steam. Allowing the steam to condense, pure hydrogen can be extracted from the shift reaction stream and carbon dioxide can be collected for sequestration. This addresses global warming issues by employing a station that produces energy with zero/low emissions.

When the chemical converter is operated as a partial oxidation or auto thermal type reformer, a fraction of the natural gas is oxidized in the presence of a combustion catalyst and a reforming catalyst. This produces a mixture of hydrogen, carbon dioxide, steam and nitrogen. The CO_2 isolation and collection is not as easy due to the presence of nitrogen diluents derived from the air required for the combustion heating.

The chemical converter may also be operated as a fuel cell. When operated as a fuel cell, electrical energy is generated with fuel supplies such as hydrogen or natural gas. When a high temperature fuel cell is used, the fuel stream is converted into CO_2 and steam without the dilution by nitrogen from the air. Following the

separation of steam by condensation, carbon dioxide can be easily collected, isolated or removed for sequestration.

The present invention forms a zero emission station with the combination a steam reformer and a high temperature fuel cell with the capacity of each being determined by the thermal energy matching of the two, wherein the reforming reaction is endothermic and the fuel cell reaction is exothermic. The reformer, as a result, has a larger capacity than the chemical matching needs of the fuel cell. Thus the excess reformed fuel can be made available for other station components, or can be delivered to a vehicle. The combination of the steam reforming and the high temperature fuel cell operation also allows for the easy capture of CO_2.

The present invention also pertains to a chemical converter configured for enhancing system operational efficiency and versatility of the overall station. The chemical converter can be disposed within a containing vessel that collects hot exhaust gases generated by the converter for delivery to a cogeneration bottoming device, such as a gas turbine. The bottoming device extracts energy from the waste heat generated by the converter yielding an improved efficiency energy system. Bottoming devices can also include, for example, a heating, ventilation or cooling (HVAC) system.

The present invention addresses the current need for clean energy production, while concomitantly addressing the need for producing energy for use by low or zero emission vehicles, which would be powered by either batteries, hydrogen fuel cells, or a combination of both. Prior to the present invention it has been possible to generate hydrogen by reforming processes in both a remote central production facility and on-site at existing automobile or truck service stations. The hydrogen can be used as fuel by low or zero emission vehicles such as hydrogen fuel cell powered vehicles. Hydrogen production can also be performed by electrolysis using utility grid power. The utility grid power can also be used to charge the batteries of the electric vehicles. This comes with substantial cost, while also burdening the electric power infrastructure. Moreover, the conventional systems for producing hydrogen generate unwanted CO_2 emissions. The continued release of CO_2 greenhouse gases at the fuel production and electric generation stations eliminates the benefits achieved from using low or zero emission vehicles. The above costs and corresponding emissions are counter-productive to the savings achieved from the use of zero/low emission vehicles.

In conventional reforming processes, including steam reforming, partial oxidation reforming or auto thermal reforming, a fraction of the natural gas is oxidized in the presence of a combustion gas, such as air, utilized by a heat source to provide heat for the endothermic reforming processes. The exhaust released into the atmosphere invariably consists of a mixture of carbon dioxide, steam and nitrogen. The carbon dioxide cannot be easily separated from the nitrogen, and hence cannot be economically sequestered. The above is true for present conventional power plants using coal, natural gas or oil.

The present invention achieves the foregoing objects and advantages by providing an energy supply station for converting hydrocarbon fuel into hydrogen and/or electricity for subsequent delivery to users, such as vehicles. The station comprises a chemical converter for processing the fuel to form an output medium containing carbon dioxide, a separation stage for separating a chemical component from the output medium, a collection element in fluid circuit with the separation stage for collecting the carbon dioxide, and a vehicle interface for interfacing with the vehicle. The vehicle interface allows for the exchange of electricity and/or hydrogen between the vehicle and the station. The station can also be configured to deliver hydrogen to another installation, or to deliver power to an electric power grid.

According to one aspect, the energy supply station includes a fuel treatment element for pre-treating the fuel prior to introduction to the chemical converter. The system can also include a vaporizer for heating and vaporizing a liquid reforming agent prior to introduction to the chemical converter, and/or an evaporator for heating and evaporating the fuel prior to introduction to the chemical converter. The vaporizer can include a steam boiler or a heat recovery steam generator.

According to another aspect, the energy supply system can include a mixer for vaporizing the reforming agent and evaporating the fuel, and/or to mix the fuel and the reforming agent.

According to another aspect, the energy supply system can further include a secondary heating stage disposed between the vaporizer and the mixer for heating the reforming agent prior to introduction to the mixer.

According to still another aspect, the chemical converter can comprise a reformer for reforming fuel in the presence of a reforming agent, and for generating an

output medium containing hydrogen, water and carbon monoxide. The reformer converts the fuel into hydrogen and carbon monoxide as a product of an intermediate reaction that occurs therein. The reforming agent can include air, water or steam. The separation stage in this arrangement can be adapted to isolate individually the hydrogen, water and carbon dioxide in the output medium.

According to still another aspect, the energy supply station, further comprises a treatment stage for treating a reforming agent prior to introduction to the reformer. The treatment stage can comprise a de-ionizer or a vaporizer. The de-ionizer processes the reforming agent with a de-ionizing resin or by a reverse osmosis technique.

According to yet another aspect, when the chemical converter is a reformer, the vehicle interface is configured to deliver hydrogen to the vehicle. When the chemical converter is a fuel cell, the vehicle interface is configured to deliver electricity to the vehicle.

According to still another aspect, the energy supply station can include a generator, which can include a fuel cell or a gas turbine assembly. The generator can be selectively coupled to the vehicle interface to deliver electricity to the vehicle.

According to still another aspect, the station can include a de-sulfurization unit for removing sulfur from the input fuel or output medium, a low and/or high temperature shift reactor for converting carbon monoxide and steam within the output medium into carbon dioxide and hydrogen, and/or a hydrogen processor for processing hydrogen present within the output medium.

Brief Description of the Drawings

The foregoing and other objects, features and advantages of the invention will be apparent from the following description and apparent from the accompanying drawings, in which like reference characters refer to the same parts throughout the different views. The drawings illustrate principles of the invention.

FIG. 1 is a schematic illustration of a low or zero emission energy supply station according to the teachings of the present invention.

FIG. 2 is a schematic block diagram illustrating the process flow of the reactants and exhaust in a low emission energy supply station.

FIG. 3 is a schematic block diagram illustrating the fluid and energy flow in a low emission energy supply station of the present invention.

Description of Illustrated Embodiments

The present invention provides for a zero/low emission energy supply station (ZES) that is adapted to primarily produce hydrogen and/or electricity for subsequent delivery to or use by a zero emission vehicle (ZEV), while at the same time eliminating or greatly reducing CO_2, SO_x, and NO_x emissions. The approach utilizes existing energy industry infrastructure with little or no changes. The supply station 302 can be adapted to include one or more components associated with the energy system 300 of FIGS. 1 and 2 .

FIG. 1 illustrates an environmentally benign (e.g., low emission) energy supply system 300 according to the teachings of the present invention. As used herein, the term zero or low emission is intended to include a supply station that has carbon emissions (including CO, CO_2 and C_xH_y species) that are 50% less than the carbon content of the hydrocarbon fuel being dispensed or consumed at the station, preferably below 25%, and most preferably close to or equal to 0%. The illustrated system 300 includes a zero/low emission vehicle 304 and a zero/low emission energy supply station 302. The station can be any size station having any desired power or hydrogen generating capacity or rating. The term "vehicle" as used herein refers to all means or modes of transportation including, but not limited to, for example automobiles, trucks, buses, trains, marine vessels, airplanes, spacecraft, transporters and the like. According to a preferred practice, the illustrated vehicle is a mobile fuel cell vehicle that employs a hydrogen consuming fuel cell and/or a rechargeable battery. Examples of vehicles suitable for use with the present invention are disclosed in U.S. Patent No. 5,858,568 and U.S. Patent No. 5,332,630, the contents of which are herein incorporated by reference. In particular, U.S. Patent No. 5,858,568 discloses the ability of a mobile fuel cell power system to couple to an off-board station. A transporter can be any apparatus configured for storing or transporting hydrogen or electricity. The illustrated vehicle 304 can include a vehicle access panel 306. The access panel 306 allows the zero/low emission energy supply station 302 to directly interface with the vehicle 304.

The illustrated energy supply station 302 can include a variety of components. According to one embodiment, the station includes a station vehicle interface 308 that is adapted to communicate with the vehicle access panel 306. The vehicle interface can be any mechanical, electrical, electromechanical, or chemical component that allows, enables or facilitates the station to interface with the vehicle in order to deliver hydrogen and/or electricity thereto. The vehicle interface 308 can optionally communicate with an optional power meter 310 and/or an optional fuel meter 312. The illustrated fuel meter 312 meters the amount of fuel exchanged between the station 302 to a fuel tank resident within the vehicle 304. The illustrated power meter 310 measures the amount of electricity exchanged between the station to the vehicle 304. According to an alternate embodiment, the electricity generated by the station 302 can be applied for charging a battery 315, or for stationary uses, such as onsite uses, uses by neighboring residential or commercial installations, or can be supplied to a local power grid through the power meter 310 or any other suitable structure.

The illustrated clean energy supply station 302 can further include a generator 314 that is in communication with the power meter 310. The generator can include any apparatus suitable for generating power or electricity, examples of which can include a fuel cell, gas turbine, steam turbine, IC generator, bottoming devices, and like apparatus. As used herein, the phrase bottoming device is intended to include any suitable structure that can be coupled to receive either power, electricity, exhaust, or thermal energy from another station component. The generator is configured to produce electricity, which can supplied to the vehicle 304 through the vehicle interface 308. The station 302 can also include an inverter 327 for inverting any electricity generated in the station. For example, if the chemical converter is a fuel cell, the inverter can invert the DC electricity generated thereby into AC electricity.

The energy supply station 302 further includes a chemical converter 316. The chemical converter 316 can be either a reformer or a fuel cell, or a hybrid system employing multiple converters for providing both functions. The chemical converter is in fluid communication with a separation stage 318, which in turn is in fluid communication with a carbon dioxide collection unit 320. The collection unit can be any device or apparatus suitable for collecting and/or storing carbon dioxide. The separation stage 318 is adapted to remove one or more constituents from the output medium generated by the chemical converter 316 or some other system component. The illustrated chemical converter can also be disposed in thermal communication with a

thermal control device 325 for system startup and thermal control during steady state operation. The chemical converter can be positioned to receive water, air or fuel depending upon the function of the chemical converter. The thermal control device is in fluid communication with a fuel and air source.

According to one practice, the illustrated chemical converter 316 can be a fuel reformer. The reformer is adapted to receive the hydrocarbon fuel and a reforming agent 324, such as water, air, steam, oxygen or carbon dioxide. Those of ordinary skill will recognize that the water can be supplied to the reformer as steam. The reformer employs a catalyst material to promote the reformation of the hydrocarbon fuel into simpler reaction species. For example, the hydrocarbon fuel can be catalytically reformed into an output medium having a mixture of H_2O, H_2, CO, and CO_2. The illustrated reformer reforms the fuel in the presence of the reforming agent to produce a relatively pure fuel stock. An example of a reformer suitable for use in the illustrated energy supply system 300 is described in U.S. Patent No. 5,858,314, the contents of which are herein incorporated by reference. According to one practice, a plate-type compact reformer can be employed in the system, although those of ordinary skill will recognize that other types of reformers, including conventional type reactant bed and cylindrical reformers, can be employed. The heat necessary for the reforming process can be supplied internally by partial oxidation of the fuel, such as a hydrocarbon fuel, or supplied externally by a heat source, such as by the thermal control device 325, a fuel cell or other heat generating type apparatus. The heat can be supplied to the reformer by radiation, conduction or convection.

The illustrated thermal control device 325 can include any selected structure for interfacing with the chemical converter 316 in order to control, adjust or regulate the temperature thereof, or of another component of the system 300. Those of ordinary skill will readily recognize that the thermal control device 325 can operate as a heating device, for example upon system start-up, or as a heat sink or cooling device during steady state operation. Examples of a suitable heating device are set forth in U.S. Patent No. 5,338,622, the contents of which are herein incorporated by reference.

When operating the reformer as a steam reformer, a preferred mode of operation, it receives a reactant gas mixture containing hydrocarbon fuel and steam. Thermal energy for the endothermic steam reforming reaction is provided externally by radiation and/or convection. This produces hydrogen in a fuel stream separate from the heating medium. The separation stage can comprise one or more stages adapted to

remove, separate or isolate individually the water, hydrogen and carbon dioxide from the output medium. Following removal or separation of the steam from the reformer output medium, such as by condensation techniques, hydrogen can also be extracted from the stream by the separation stage 318, and the remaining carbon dioxide can be collected, sequestered or stored in the carbon dioxide collection unit 320. The output reformed fuel, or hydrogen, generated by the reformer can be supplied to the vehicle 304 through the vehicle interface 308. Alternatively, the hydrogen can be stored in the fuel storage unit 322 resident within the station 302. The fuel storage unit 322 can be any suitable storage element, and can be formed of metal or fiberglass, or from a polymer-lined composite material, such as the Type IV TriShield storage tank of Quantum Technologies, Inc., U.S.A..

When the steam reforming described above is employed, air is not mixed with the fuel, and hence the difficult to remove nitrogen by-products are not present in the converter output medium. This is diametrically opposite to a partial oxidation or auto thermal reforming reformer, where a fraction of the natural gas is oxidized in the presence of a combustion and reforming catalyst. The reformer consequently produces a mixture of hydrogen, carbon dioxide, steam and nitrogen.

Those of ordinary skill will readily recognize that a treatment unit, such as a de-ionization or vaporizer unit, can be provided to pretreat the reforming agent 324 prior to introduction to the chemical converter 316. The type of reforming agent processor can be selected depending upon the type of reforming agent used, or the type and/or configuration of the chemical converter 316. If the reforming agent is water, the processor can process the agent with a de-ionizing resin device or with a reverse osmosis device.

The illustrated separation stage 318 is adapted or configured to separate or remove one or more selected components from the output medium generated by the chemical converter 316. According to one practice, the separation stage is adapted to remove one or more components so as to leave carbon dioxide within the output medium. The remaining carbon dioxide can then be captured and collected within the carbon dioxide collection unit 320. Those of ordinary skill will readily recognize that the carbon dioxide can be removed from the chemical converter exhaust directly, or can be left in the exhaust upon removal of one or more other exhaust components, such as hydrogen.

The separation stage 318 can be any suitable stage adapted or configured for separating one or more components from the output medium of the chemical converter. The separation stage can be configured for separating hydrogen or carbon dioxide from the output medium. The separation stage can be configured to separate hydrogen or carbon dioxide from the output medium according to a number of techniques, including but not limited to chemical or physical absorption, adsorption, low temperature distillation, high pressure liquefaction, membrane, enzyme, and molecular sieve type separation techniques. One example is an enzymatic process technique conducted in an aqueous environment that transforms CO_2 and H_2O into H^+ and HCO_3^-. The bicarbonate (HCO_3^-) is an environmentally safe species suitable for controlled disposal.

When the chemical converter 316 functions as a reformer, the reformed fuel can be stored in the fuel storage unit 322 or in a storage unit in the vehicle 304. The storage units can include appropriate storage media suitable for storing or transporting hydrogen. The storage media can also refer to the manner in which the hydrogen is transported within the container or the state of the hydrogen within the container. The hydrogen can be stored or transported in a compressed gas state (H_2), a solid state (such as a metal hydride), an aqueous state (such as a liquid hydride including $NaBH_4$, KBH_4, and $LiBH_4$), or in a liquid or refrigerated state (such as liquefied hydrogen). The aqueous storage or transport of hydrogen can employ any suitable chemical reaction, such as by reacting $NaBO_2$ with $4H_2$ to form $NaBH_4$ and $2H_2O$. The release of hydrogen occurs in the reverse direction in the presence of any suitable known catalyst. The aqueous solution is a particularly suitable form of storing hydrogen since existing practices of gasoline storage and transporting vehicles can be employed.

The energy supply station 302 can also include apparatus for further conditioning the fuel or reformed fuel, such as a desulfurization unit, a hydrogen shift reactor, a hydrogen polisher, or a hydrogen compressor for compressing hydrogen. The compressor can be a mechanical or an electrochemical compressor, such as a phosphoric acid, alkaline, or proton exchange membrane device.

In operation, the hybrid energy supply station 302 can generate hydrogen and/or electricity that can be supplied to the vehicle 304. When the chemical converter is a reformer, the station includes means for supplying a reforming agent, such as air, water, or both, and fuel to the reformer. The reformer output medium generally includes hydrogen rich gas. The output medium can then be passed through the separation stage

to separate one or more constituents, such as hydrogen or CO_2. The hydrogen can then be transferred to a zero or low emission vehicle 304 through the vehicle interface 308. The fuel meter 312 can determine the amount of fuel supplied to the vehicle 304. The hydrogen fuel can also be provided to the generator 314, which in turn generates electricity and exhaust. The electricity can also be supplied to the vehicle 304 through the vehicle interface 308.

The chemical converter 316 can also be operated as an electrochemical device, such as a fuel cell. When operated as a fuel cell, the device consumes fuel and an oxidant to generate electrical energy and a high temperature output medium. When a solid oxide fuel cell is used, the fuel stream output medium includes carbon dioxide and steam without being diluted by nitrogen. Following removal of steam from the output medium by the separation stage 318, such as by condensation techniques, the remaining carbon dioxide can be collected and stored in the collection unit 320. Moreover, the high temperature output medium can also be conveyed to the generator, which in turn generates additional electricity. The electricity can be supplied to the vehicle 304 through the interfaces 306 and/or 308. The term fuel cell as used herein is intended to include any suitable fuel cell, such as the plate-type fuel cell described in U.S. Patent No. 5,501,781 and 4,853,100, the contents of which are herein incorporated by reference, or a rectangular, square or tubular type fuel cell. The fuel cell can be either a molten carbonate fuel cell, a phosphoric acid fuel cell, an alkaline fuel cell, or a proton exchange membrane fuel cell, and is preferably a solid oxide fuel cell.

According to another practice, the chemical converter can be disposed within a containing vessel that collects hot exhaust gases generated by the converter for delivery to a generator or bottoming plant, such as a gas turbine. A suitable vessel adapted to enclose the chemical converter 316 is disclosed and described in U.S. Patent No. 5,501,781, the contents of which are herein incorporated by reference. The bottoming device extracts energy from the waste heat generated by the converter yielding an improved efficiency energy system. Bottoming devices can also include, for example, a heating, ventilation or cooling (HVAC) system.

Those of ordinary skill will readily recognize that any suitable number of chemical converters, thermal control devices, generators and separation stages can be employed. According to a preferred embodiment, the station 302 includes one or more fuel cells and one or more reformers for generating hydrogen and electricity.

A significant advantage of the present invention is that the energy supply station can be operated in a hybrid mode, thereby generating and supplying hydrogen and electricity to the zero or low emission vehicle 304. According to one practice, the reformer generates amounts of reformed fuel larger than that required by the fuel cell. Thus, the excess reformed fuel can be made available for hydrogen production.

Another advantage of the energy supply station 302 of the present invention is that it facilitates or promotes the use of zero or low emission electric or fuel cell vehicles. The station 302 of the present invention can supply electricity and hydrogen for the vehicle 304 by converting onsite conventional transportation fuel. Such an approach allows the station to employ or interface with present day infrastructure, such as electric supply grids and fuel supply trucks and pipelines. Moreover, the onsite distributed energy supply system of the station 302 utilizes, according to one aspect, a high temperature fuel cell system for electric generation and a steam reforming system for hydrogen production. These systems are desirable approaches since they offer high system efficiency, high system utilization, and relatively easy carbon dioxide sequestration. By simplifying carbon dioxide sequestration, the station promotes the formation and use of zero/low emission installations.

FIG. 2 is a schematic block diagram illustrating the process flow of the reactants and output medium according to the teachings of the present invention. Like reference numerals are used throughout to designate like components. The illustrated system or station 302 is intended to be simply illustrative of the operation and interrelationship of certain components of the foregoing systems. Although illustrated with multiple different stages and components, the system can have any selected number of components and arrangements thereof. The illustrated arrangement is merely illustrative and is not intended to be construed in a limiting sense. The description of stages and components previously described need not be reproduced below. As illustrated, the system employs two chemical converters, a fuel cell 112 and a reformer 110.

The reforming agent 88, such as water, is introduced to the treatment stage 92, and is then transferred to the vaporizer 94. The vaporizer heats the water and converts it to steam, which is then conveyed to the mixer 176. The vaporizer can be a steam boiler or a heat recovery steam generator. According to an alternate optional embodiment, a secondary heater can be positioned between the vaporizer 94 and the mixer 176 to further heat the gaseous reforming agent exiting the vaporizer prior to

introduction to the mixer 176. The fuel is introduced to the treatment stage 96, and is then introduced to the mixer 176. The mixer 176 mixes the reforming agent and the fuel prior to introduction to the reformer 110. The mixer also serves as an evaporator if liquid fuel is used and the steam is the source of heat for this process. The evaporator heats and evaporates the fuel. The reformer 110 preferably reforms the fuel in the presence of the reforming agent and a catalyst to create an output medium having one or more of H_2O, H_2, CO, CO_2, and S. The hydrogen and/or other components of the output medium can be introduced to the fuel cell 112. The fuel cell electrochemically converts the reformed fuel in the presence of an oxidant into electricity while concomitantly producing an output medium or exhaust primarily comprised of H_2O and CO_2. The fuel cell output medium 75 can be a high temperature medium that can be transferred to a bottoming plant, such as the gas turbine 74 or an HVAC unit. The bottoming plant can produce exhaust, such as nitrogen, and electricity that can be conveyed to other sites or users. Conversely, the bottoming plant can receive an input medium, such as air, and produce an output stream that is introduced to the fuel cell 112. The output stream can be a medium compressed by the bottoming plant, or an output effluent suitable for processing by the fuel cell. The electricity generated by the fuel cell can be extracted therefrom and used for any desired purpose. For example, the electricity can be used onsite, used nearby, supplied to an electrical utility grid 402 for normal power purposes, or it can be used to charge a battery 404, such as the type employed in electric vehicle 304.

The output medium of the reformer 110 can then be conveyed to a second treatment stage 406. The treatment stage 406 can be any suitable stage for processing or conditioning the fuel, examples of which include a desulfurization unit. The desulfurization unit can employ ZnO to absorb or remove sulfur from the output medium. The treated output medium can then be introduced to an additional treatment stage 412, which for example can include high and low temperature shift reactors converting CO in the presence of H_2O into H_2 mixed with CO_2. The high temperature shift reactor can comprise a reactant bed of Fe_2O_3/Cr_2O_3 material that chemically reacts with the output medium, and the low temperature reactant bed can comprise a reactant bed of CuO/ZnO for chemically reacting with the output medium. Heat exchangers can be provided at appropriate locations to ensure that the proper temperature is attained during the processing steps.

The system 300 further includes a water separation stage for removing water from the output medium. The water can be removed for example by known condensation techniques.

The output medium of the zero/low emission hybrid electric supply station then typically includes H_2 and CO_2, which can be introduced to a separation stage. For example, the separation stage 318 of FIG. 1 separates either CO_2 or H_2 from the output medium. According to one practice, the separation stage separates hydrogen from the output medium according to any of the above-described art known techniques. The CO_2 remaining in the output medium with hydrogen rich gas, without the dilution of extraneous and unwanted N_2, can be easily sequestered and stored in the collection unit 320. This forms a zero/low emission station since the CO_2 is not vented or exhausted into the environment. The above technique utilizing steam assisted reforming and the waste heat derived from the high temperature fuel cell make it possible for simple CO_2 isolation. The N_2, a benign species in the remaining oxidizer stream of the fuel cell operation, is passed along through a bottoming device, such as a gas turbine and HVAC stage, and vented separately to the ambient environment.

The zero emission system of the invention employs a combination of the above steam reformer and high temperature fuel cell, where the capacity of each is determined by the thermal energy matching of the two, such that the reforming reaction is endothermic and the fuel cell reaction is exothermic. The reformer, as the result, has a bigger capacity than the chemical matching needs of the fuel cell. Thus the excess reformed fuel can be made available for hydrogen production. The combination of the steam reforming and the high temperature fuel cell operation allows for the total capture of CO_2. Moreover, the system of the present invention achieves total system energy balance without additional combustion heating. The ratio of the co-production of electrical energy to hydrogen fuel energy in this environmentally benign system is about 2 to 1. The system 300 has an electrical efficiency of about 45% and a chemical production rate of about 25% resulting in a system co-production efficiency of about 70%. This can provide the electricity necessary to charge the battery of an electric vehicle at the station; to supply electricity for the station operation; provide electricity for surrounding commercial electrical needs; and can also provide hydrogen for a fuel cell vehicle refueling at the station. The system can be operated in an off-design condition where a smaller proportion of the hydrogen reforming product is generated, and results in a system of less than optimum efficiency. On the other hand, the off-design condition of the station 302 can be employed to generate amount of electricity,

which requires an incremental additional amount of combustion to occur to support the reforming process, thereby resulting in relatively low levels of CO_2 emission.

The system 300 can be equipped with a sulfur removal device to control the SOx emission, and can be arranged to include a fuel cell stage which operates according to electrochemical principles, and below 1000 °C, and eliminates the formation of NOx in the process.

A significant additional advantage of the energy supply station 302 of the invention is that it achieves total system energy balance without requiring additional fuel and air combustion components. The station can share components of both a reformer system and a fuel cell system, and is capable of providing diverse energy services in a baseload operation. The attractiveness of the system is the environmental advantages, such as zero emission, in an economical station arrangement.

The hydrogen separated from the output medium of the chemical converter can also be processed and/or stored by stage 416 of FIG. 2. The captured hydrogen can be made available for consumption on- or off-site. For example, the hydrogen can be provided to fuel cell vehicles with hydrogen tanks, or can be made available to the on-site generator 314 in order to produce additional power and electricity.

FIG. 3 illustrates another embodiment of the station 302 according to the teachings of the present invention showing the energy and fluid flows occurring therein. Like reference numerals are used throughout to designate like parts. Although illustrated with multiple different stages and components, the station can have any selected number of components and arrangements thereof. The illustrated arrangement is merely illustrative and is not intended to be construed in a limiting sense. The description of the stages and components previously described need not be reproduced below. The illustrated station 302 illustrates a high efficiency co-production system that includes a steam reformer positioned to reform an input fuel in the presence of a reforming agent and a catalyst into a hydrogen rich output medium. A portion of the reformed fuel can be introduced to the fuel cell 112, where it electrochemically reacts with an oxidizer reactant, such as air, to produce an output exhaust and electricity 428. The reformer can utilize the waste heat from the fuel cell as the process heat 422 to conduct the reforming reaction. The remaining portion of the hydrogen rich output medium 424 can be used for other purposes.

The illustrated fuel cell 112 produces an output exhaust that can be introduced to an optional gas turbine assembly 74, which converts the exhaust into rotary energy. The gas turbine produces electricity 428 and an exhaust stream, which in turn is introduced to a boiler, such as a heat recovery steam generator (HRSG) 420. The turbine exhaust introduced to the HRSG converts an input fluid 430, such as water, into steam 426 as it passes therethrough. The resultant steam 426 produced by the HRSG can be utilized by the reformer 110 to reform the input fuel.

The illustrated station 302 employs a fuel cell, reformer, and an optional turbine to form an energy efficient power station having about 45% electrical efficiency plus a 25% chemical efficiency, resulting in an electrical /chemical co-production efficiency of about 70%. The performance of this integrated fuel cell/reformer system is, as shown in FIG. 3, enhanced by the full utilization of the waste heat from the high temperature fuel cell to provide the reformer with the process heat 422 and the process steam 426 for reforming reaction.

As used herein, the term hydrogen is intended to include a fluid or gas rich in hydrogen, and may include any number of other types of fluids, gases or gas species, such as residual gases including CO_2, CO, H_2O, and unprocessed or unreformed fuel.

It will thus be seen that the invention efficiently attains the objects set forth above, among those made apparent from the preceding description. Since certain changes may be made in the above constructions without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings be interpreted as illustrative and not in a limiting sense.

It is also to be understood that the following claims are to cover generic and specific features of the invention described herein, and all statements of the scope of the invention which, as a matter of language, might be said to fall therebetween.

Having described the invention, what is claimed as new and desired to be secured by Letters Patent is: